

Preliminary Analysis of TF Joint Behavior*

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NSTX Team Meeting

2/12/4

**Summary from 1/29/4 Presentation*

Outline

- Overall Questions to be Addressed
- Description of Measurements
- Measurements from ISTP Shots
- Measurements vs. Analysis
- Measurement Trends
- Issues & Follow-on Work

Questions To Be Addressed

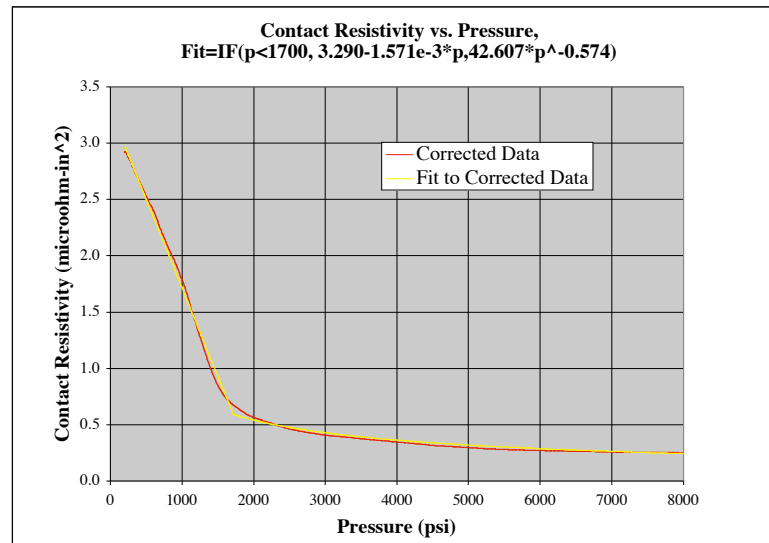
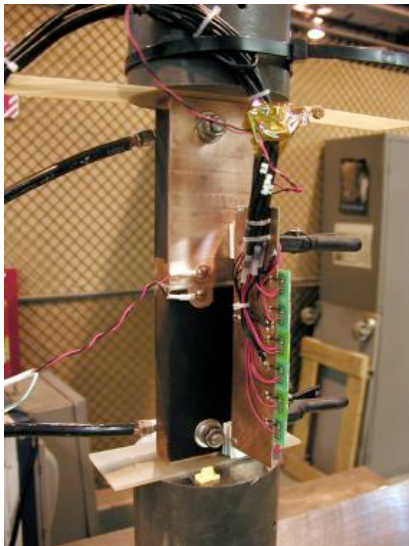
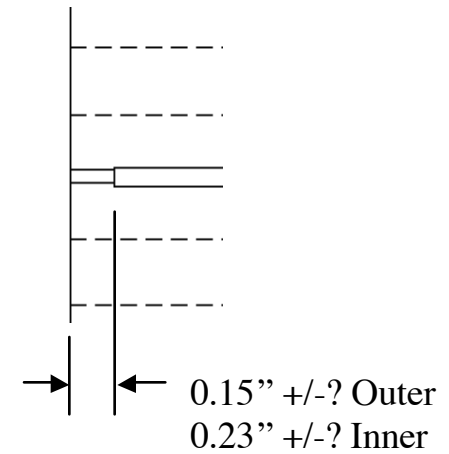
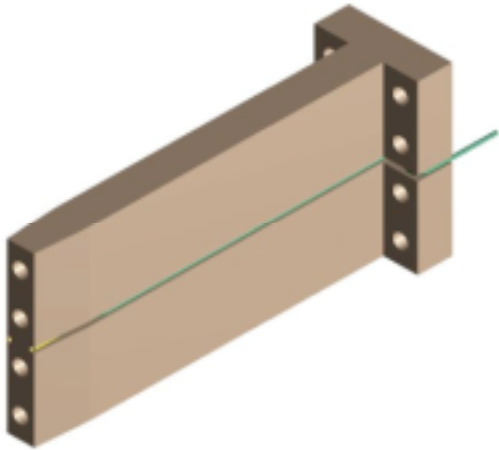
- 1) Does measured behavior agree with analytic model?
 - How much difference between measurements and predictions?
 - Does model need to be changed?
 - Does operating envelope need to be reconsidered?

- 2) Do all joints of the same type behave the same way?
 - What variation exists joint-to-joint?
 - Are any joints significantly different than others?

- 3) Is behavior changing as more load cycles are applied?

Resistance Measurements

$$R = R_{\text{bulk}} + R_{\text{contact}}$$



- Outer:
 - Predicted 75nOhm
 - Measured 40nOhm avg.
- Inner:
 - Predicted 95nOhm
 - Measured 75nOhm avg.

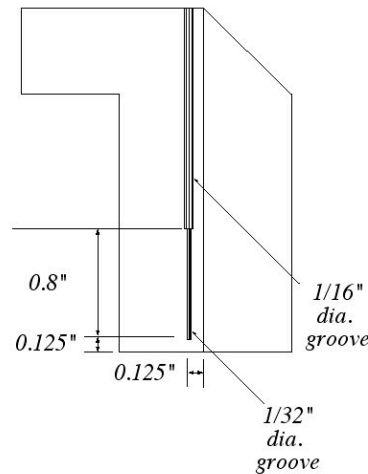
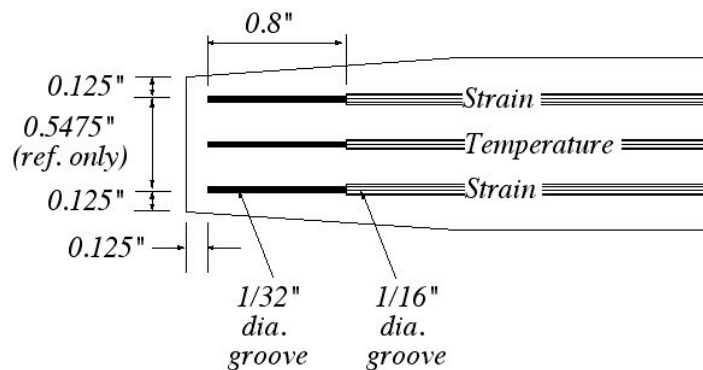
Fiber Optic Temperature, Strain, Displacement Measurements

- Four Flags (inner, outer/top, bottom)
 - ✓ 4 flags x 3 strain/flag = 12 strain
 - ✓ 4 flags x 1 temp/flag = 4 temp
- Hub and Flag twist angle (inner, outer/top, bottom)
 - ✓ 4 displacement
- Spline (top only)
 - ✓ 1 displacement

Total 21 transducers



8 conditioner channels



FISO Technologies, Inc.

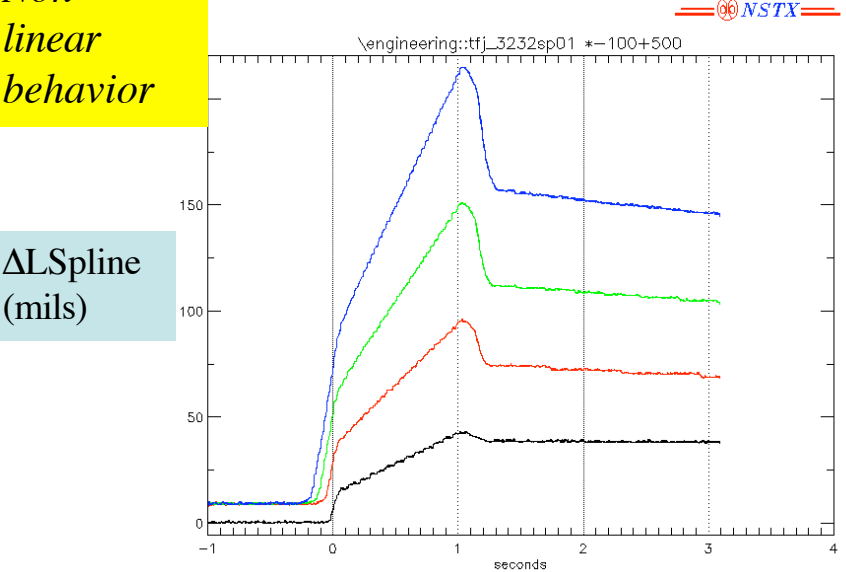
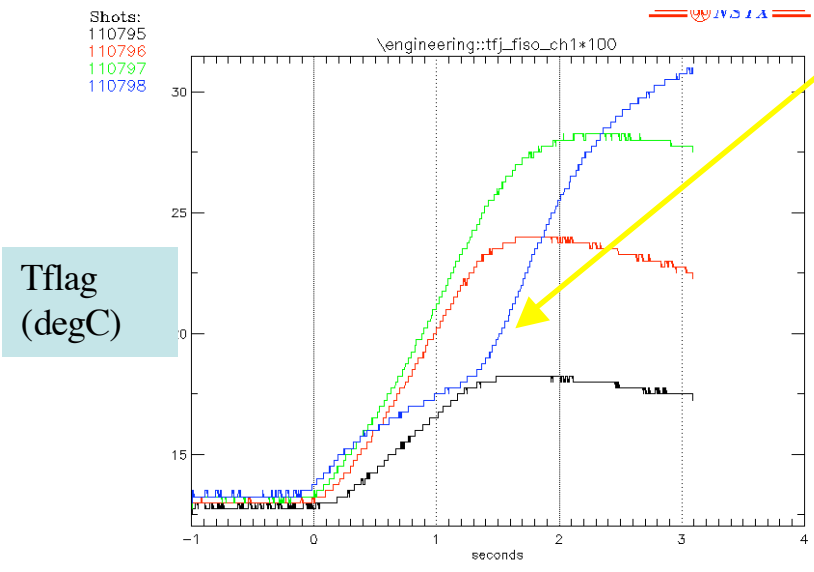
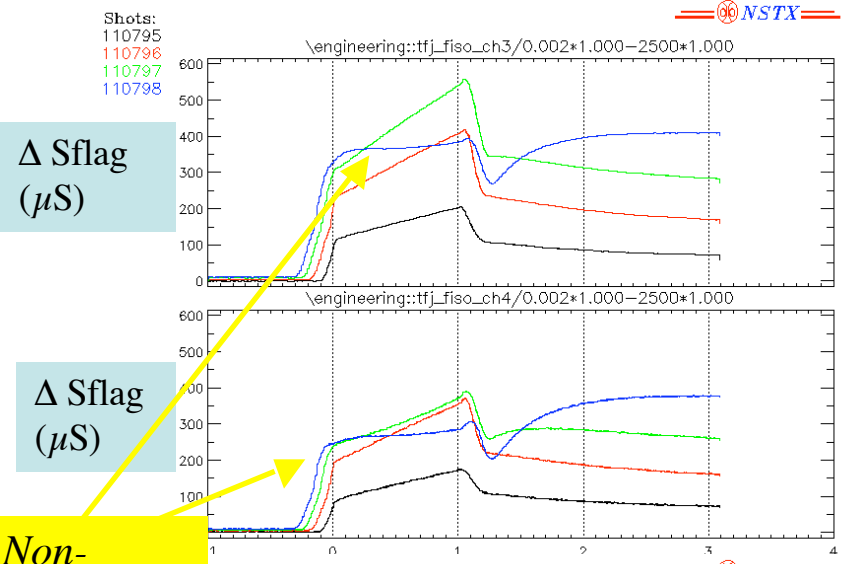
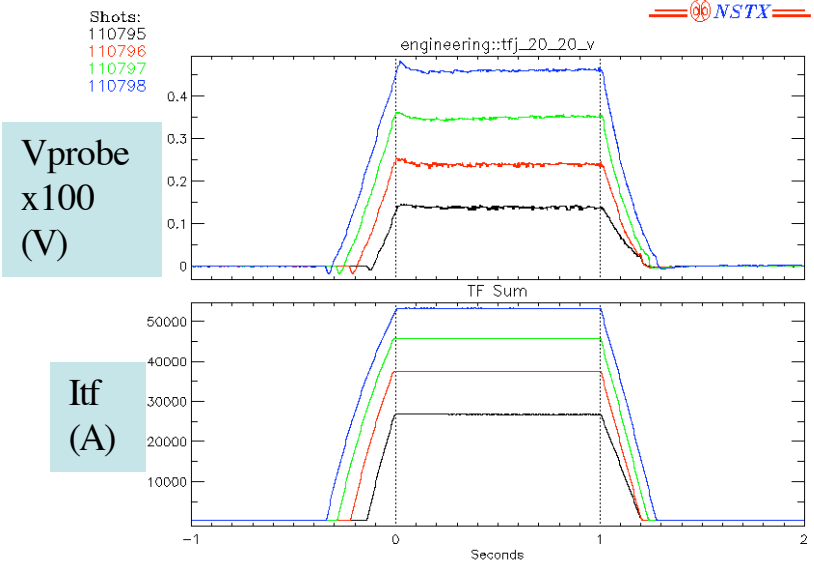
ISTP-001 Shot & Signal List

14 shots 1/16-1/20

Shot	Date	Itf (kA)	PF/OH (%)	Comments	FISO#1	FISO#2	FISO#3	FISO#4	FISO#5	FISO#6	FISO#7	FISO#8	19_19 Probes
110752	1/16/04	26.7	0	Analysis Case #1	Top Outer Flag Temp FOE#8	Bot Inner Flag Temp FOE#13	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Bot Inner Flag Strain FOE#12	Top Inner Flag Strain FOE#2	Top Inner Flag Strain FOE#1	TFJ_19_19_V=B
110755	1/16/04	37.8	0	Analysis Case #2	Top Outer Flag Temp FOE#8	Bot Inner Flag Temp FOE#13	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Inner Flag Strain FOE#2	Top Inner Flag Strain FOE#1	TFJ_19_19_V=B
110757	1/16/04	46.2	0	Analysis Case #3	Top Outer Flag Temp FOE#8	Bot Inner Flag Temp FOE#13	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Inner Flag Strain FOE#2	Top Inner Flag Strain FOE#1	TFJ_19_19_V=B
110758	1/16/04	53.4	0	Analysis Case #4	Top Outer Flag Temp FOE#8	Bot Inner Flag Temp FOE#13	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Inner Flag Strain FOE#2	Top Inner Flag Strain FOE#1	TFJ_19_19_V=B
110790	1/19/04	26.7	0	Repeat of Analysis Case #1	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B
110791	1/19/04	37.8	0	Repeat of Analysis Case #2	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B
110792	1/19/04	46.2	0	Repeat of Analysis Case #3	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B
110793	1/19/04	53.4	0	Repeat of Analysis Case #4	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Inner Flag Strain FOE#14	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B
110795	1/20/04	26.7	0	Repeat of Analysis Case #1	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
110796	1/20/04	37.8	0	Repeat of Analysis Case #2	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
110797	1/20/04	46.2	0	Repeat of Analysis Case #3	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
110798	1/20/04	53.4	0	Repeat of Analysis Case #4	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#5	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
110799	1/20/04	26.7	50	Analysis Case #5	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#4	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
110803	1/20/04	53.4	100	Analysis Case #6	Top Outer Flag Temp FOE#8	Top Shear Key Strain FOE#4	Top Outer Flag Strain FOE#6	Top Outer Flag Strain FOE#7	Bot Outer Shear Key Strain FOE#15	Axial Delta L FOE#19	Top Outer Flag Rotation FOE#17	Bot Inner Flag Rotation FOE#20	TFJ_19_19_V=B TFJ_SPARE_01=A
					Notes:								
					Changed from TFJ_FISO_CH 2 to TFJ_3232SP0 2 1/20 11:00 am after 110798					Changed from TFJ_FISO_CH 6 to TFJ_3232SP0 1 1/20 9:00 am after 110793			

TF-only Shots (110795, 6, 7, 8)

- 53.4kA shot non-linearity
- LH/RH Strain gauges disagree at 46.2 & 53.4kA

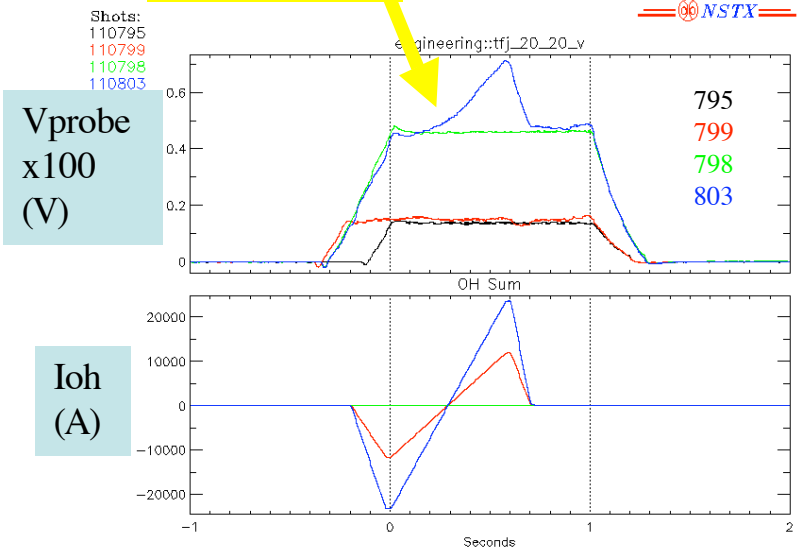


Non-linear behavior

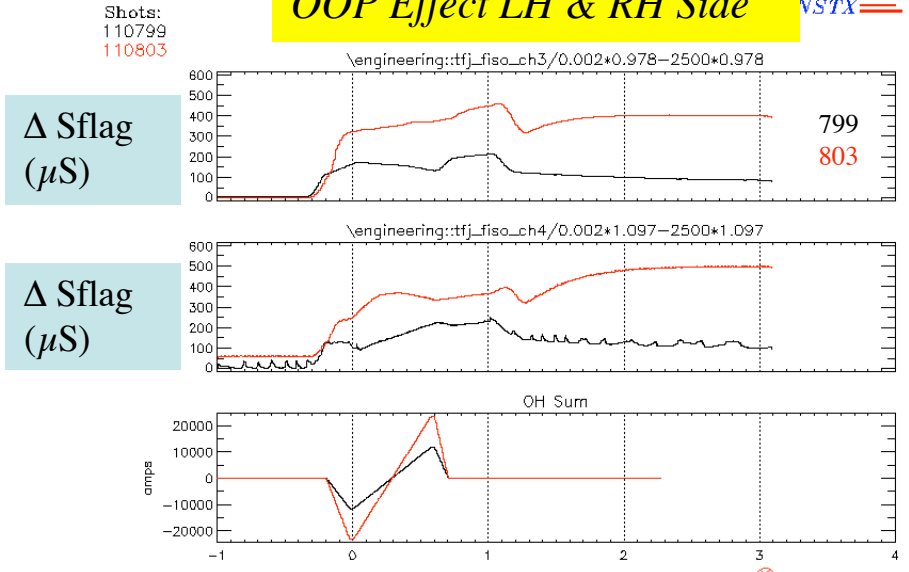
ΔLSpline (mils)

Combined Field Shots (110799,803)

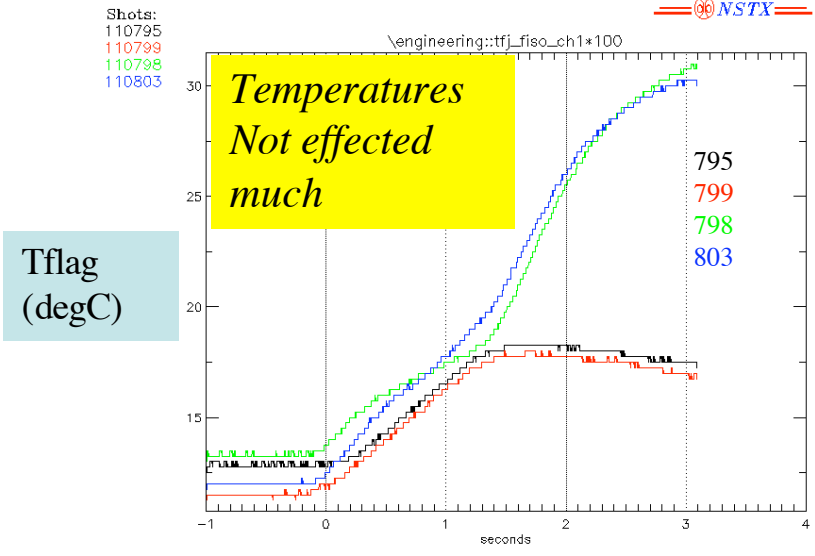
OOP Effect



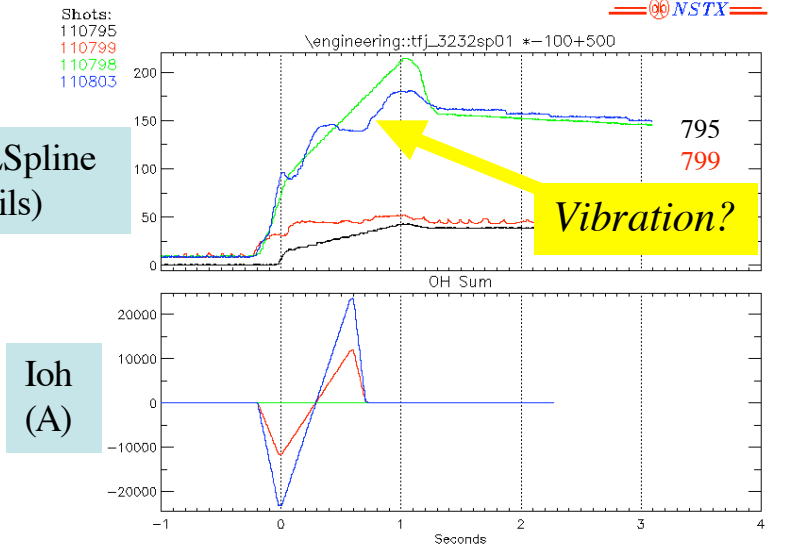
OOP Effect LH & RH Side



Temperatures Not effected much



ΔLSpline (mils)



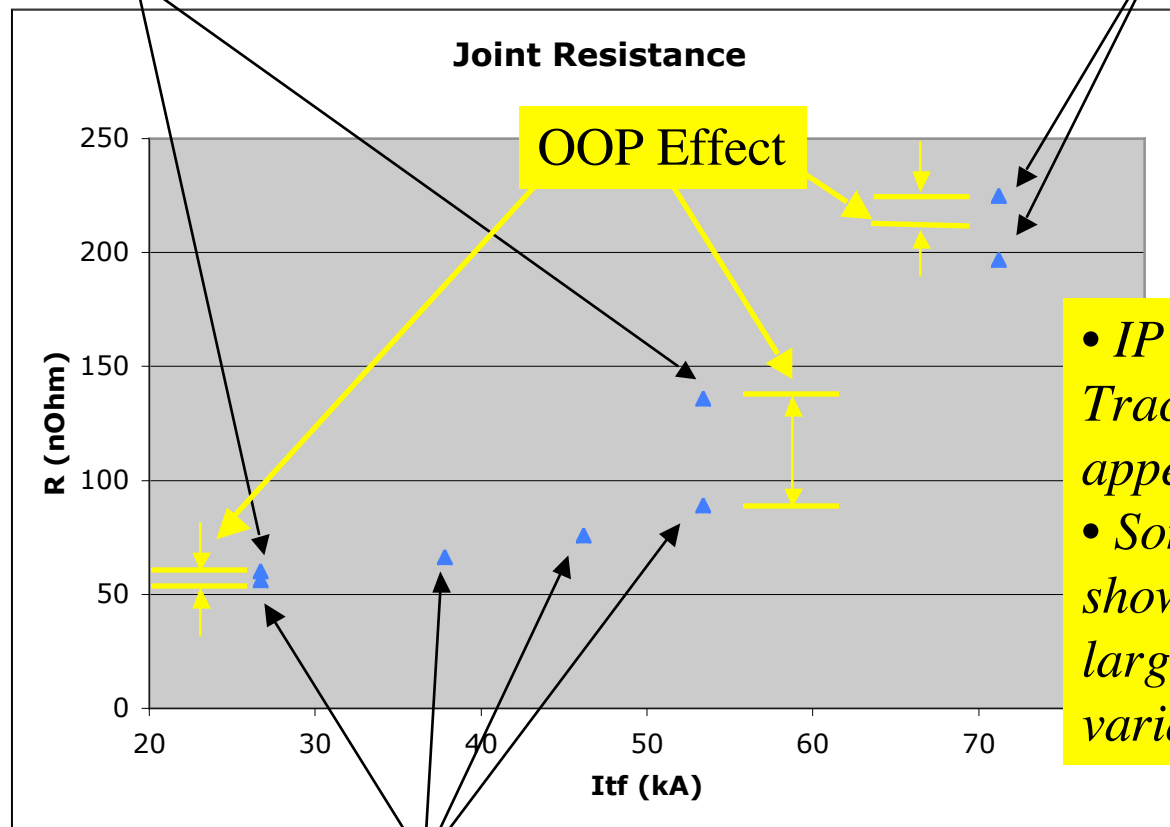
Vibration?

Analysis vs. Measurements - Resistance

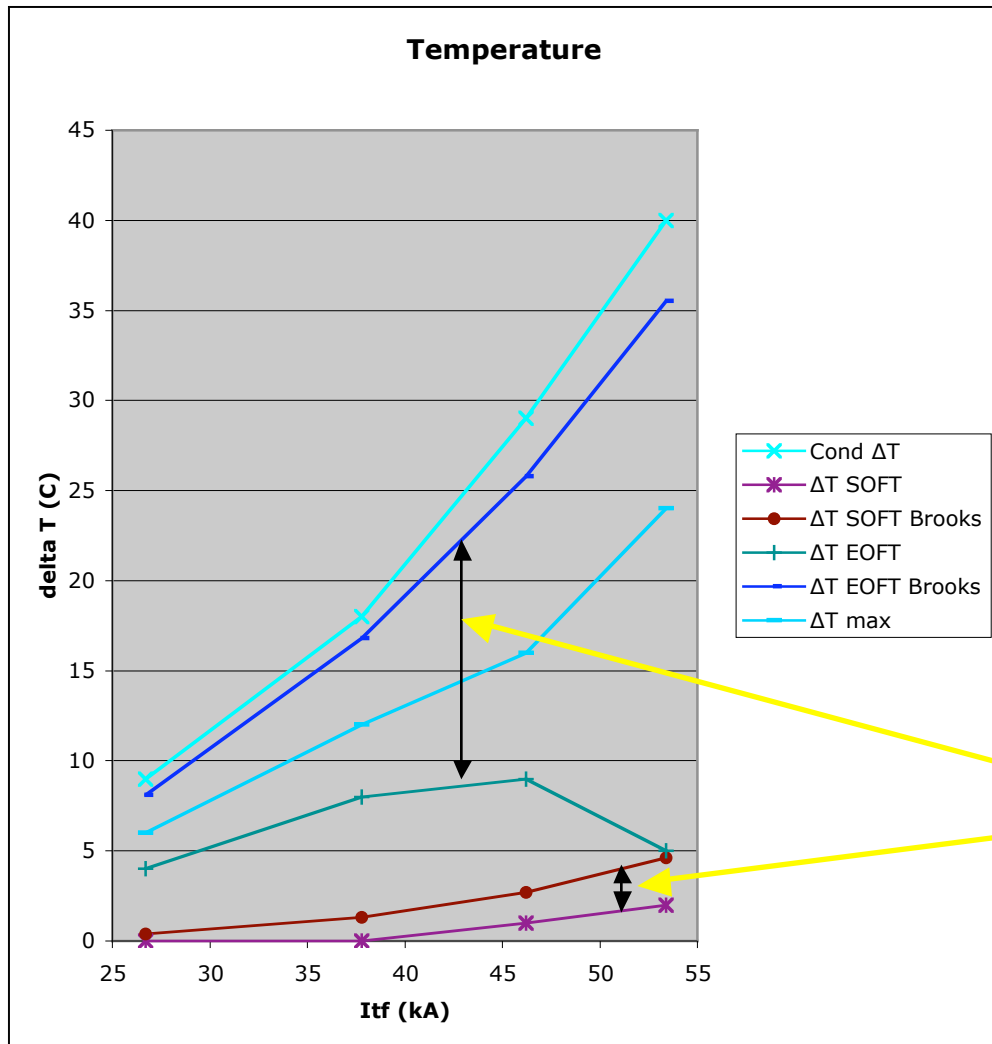
20_20 = Outer/Top

Brooks Analysis
(two sides of joint,
Combined TF-PF)

Combined TF-PF (max time point)



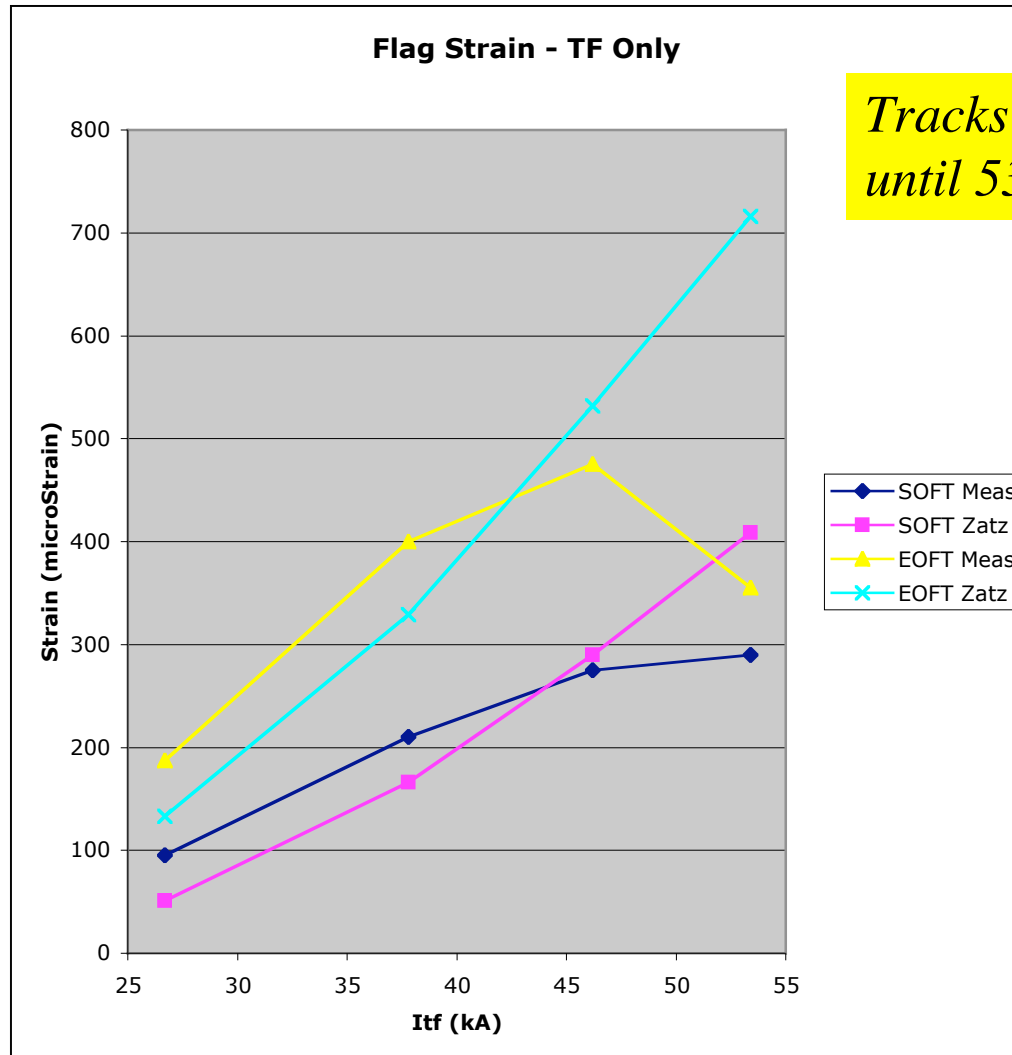
Analysis vs. Measurements - Temperature



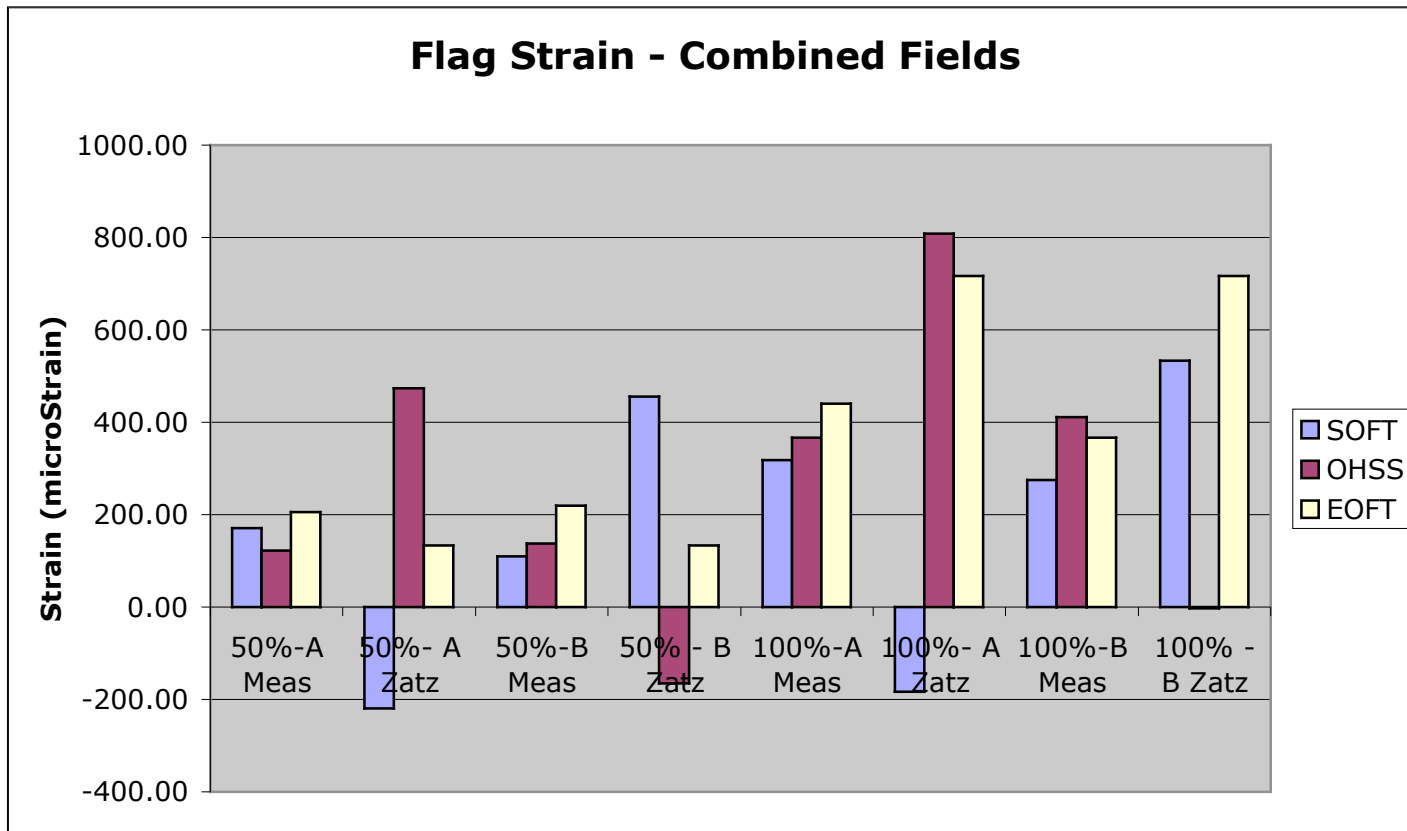
Discrepancies may arise from...

- probe response*
- probe averaging over length*
- non-linear behavior*
- inc'l contact thermal conductivity*

Analysis vs. Measurements - Strain (TF-Only)

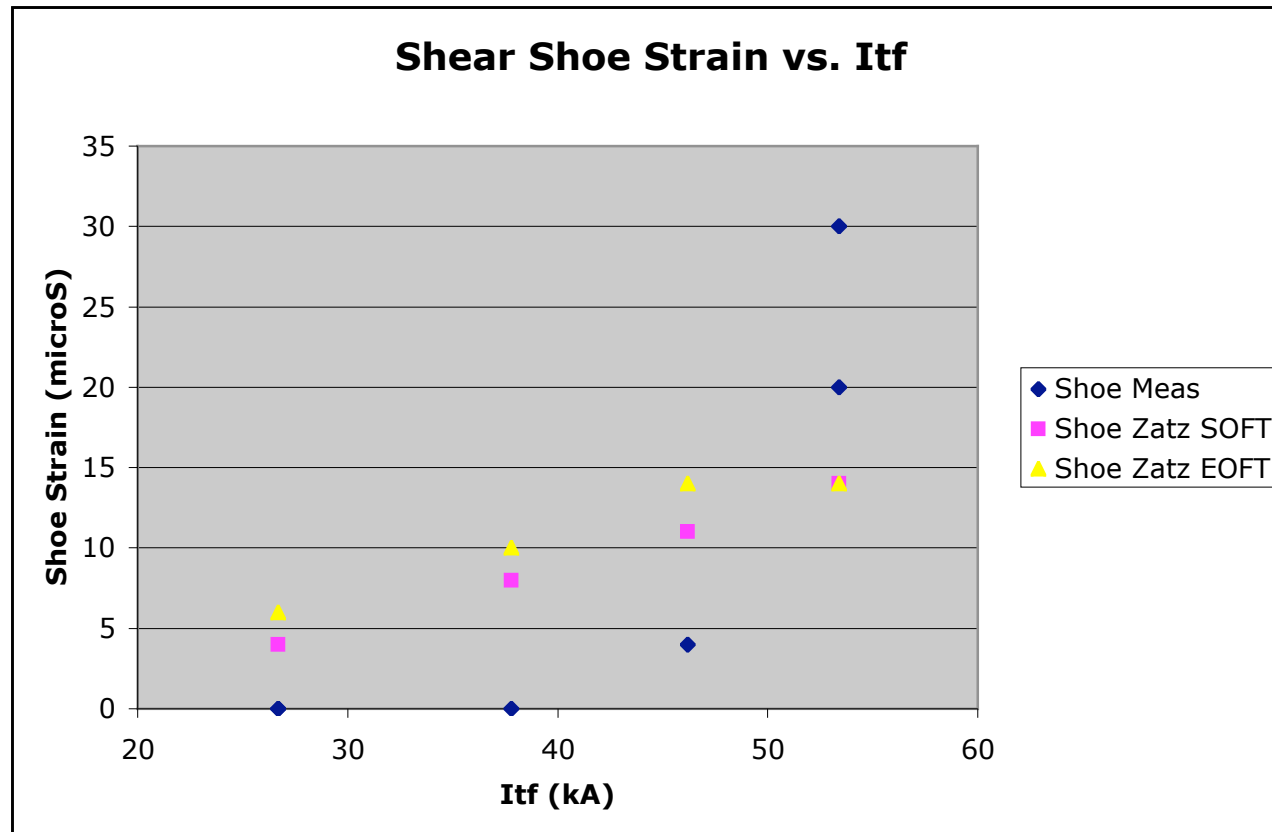


Analysis vs. Measurements - Strain (con't)



- *Analysis predicts more OOP strain variation than measured*
- *Analysis predicts more EOFT strain than measured*

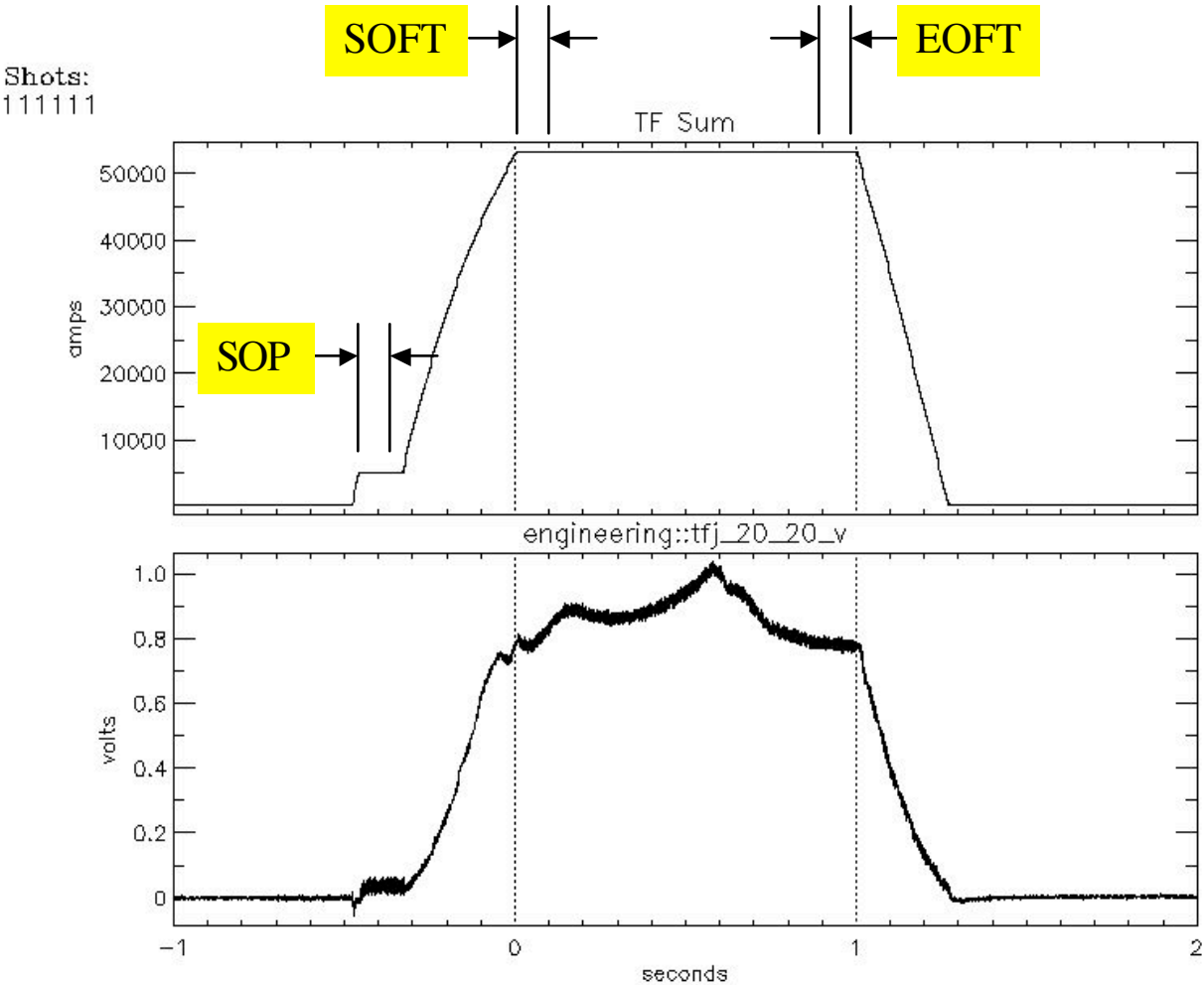
Analysis vs. Measurements - Strain (con't)



- *Analysis overestimates up to 46.1kA, underestimates at 53.4kA*

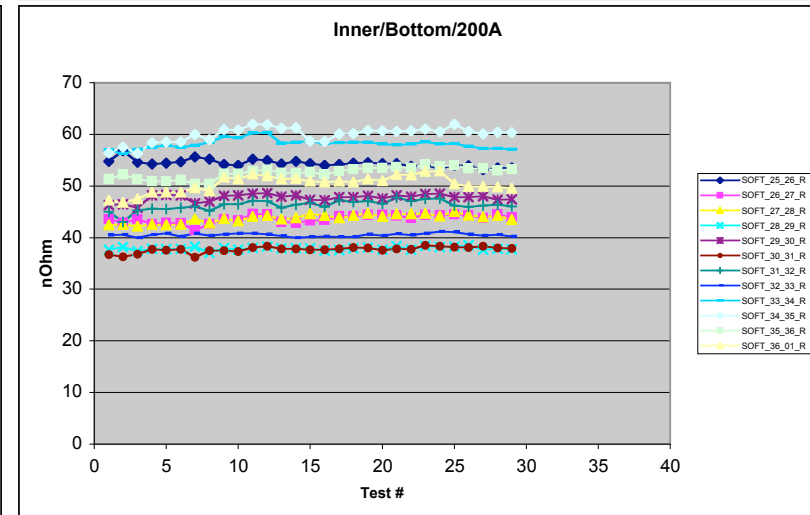
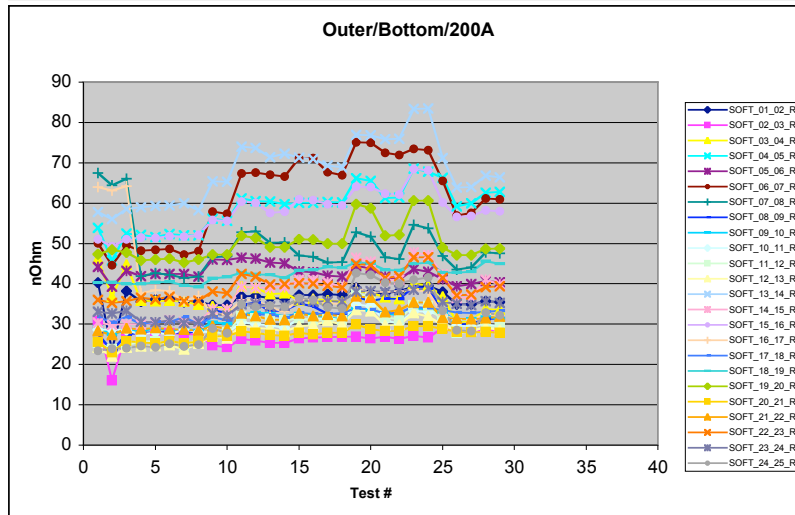
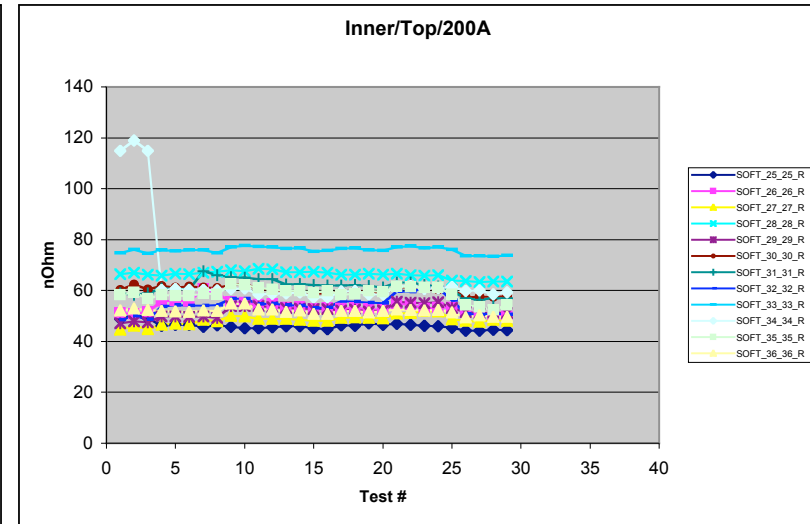
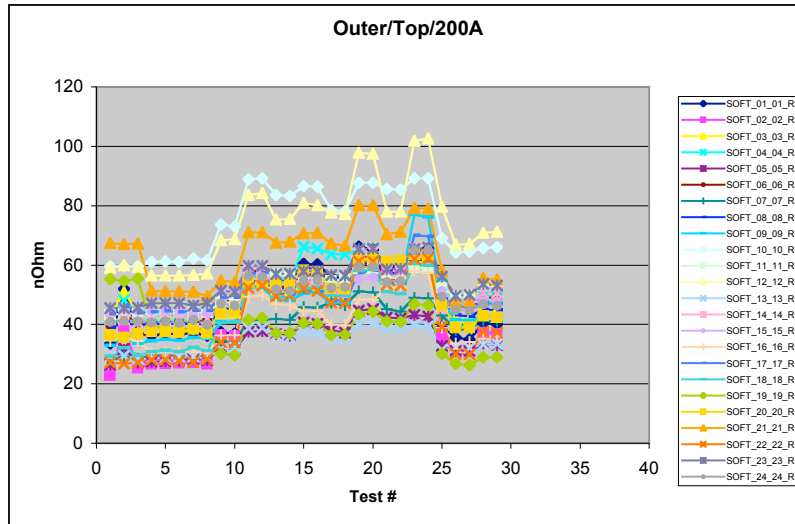
Trending of Resistance Measurements

(H. Schneider/R.Marsala/D. Mastrovito)



$$R = V_{avg}/I_{avg} \text{ over interval}$$

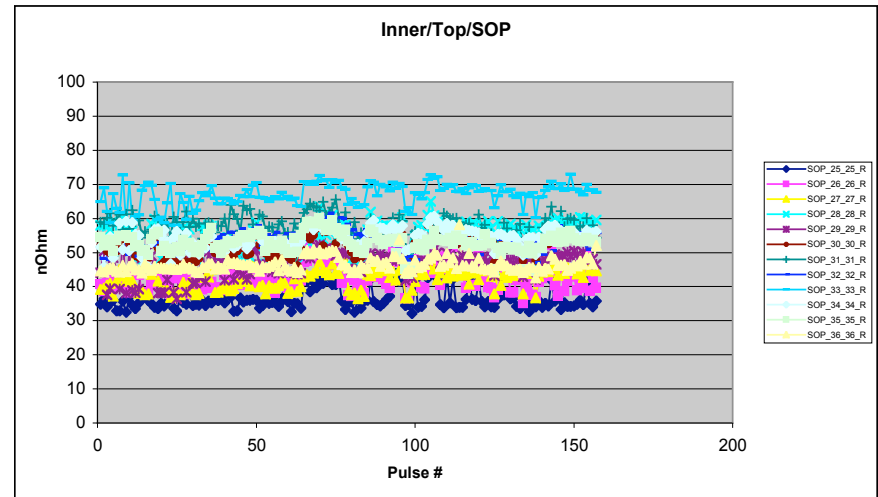
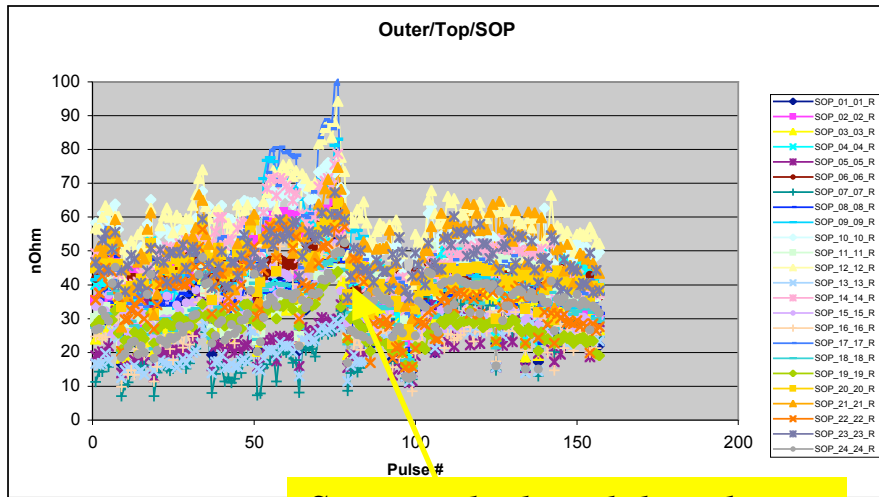
200A Trend from 1/12 to 2/6/04



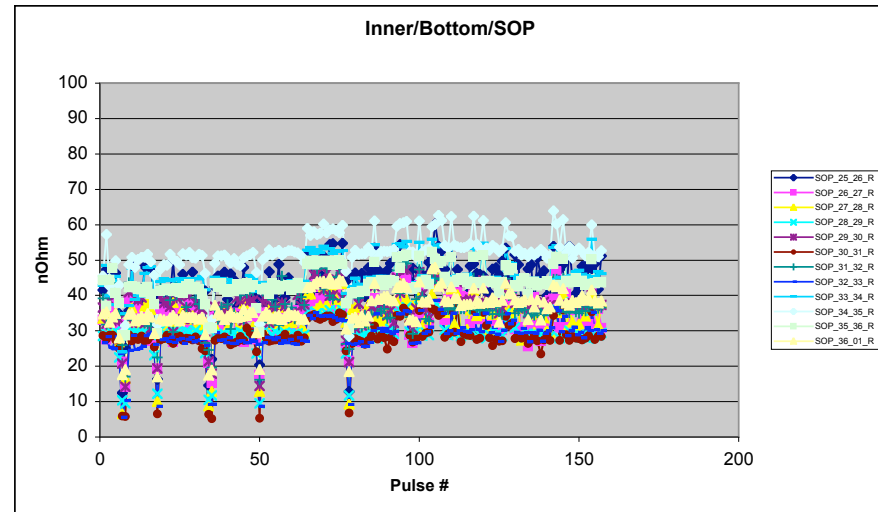
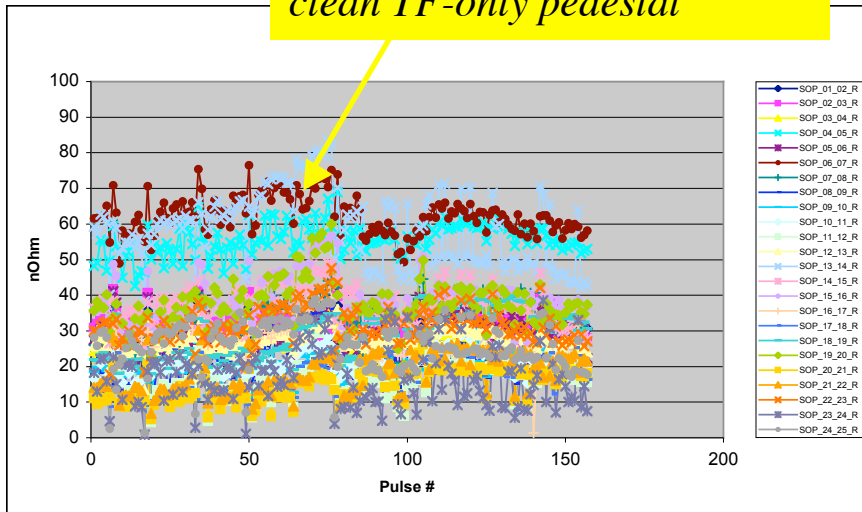
Data includes 2 measurements at 2 gains per test

5kA SOP Trend

Last 200 shot #'s

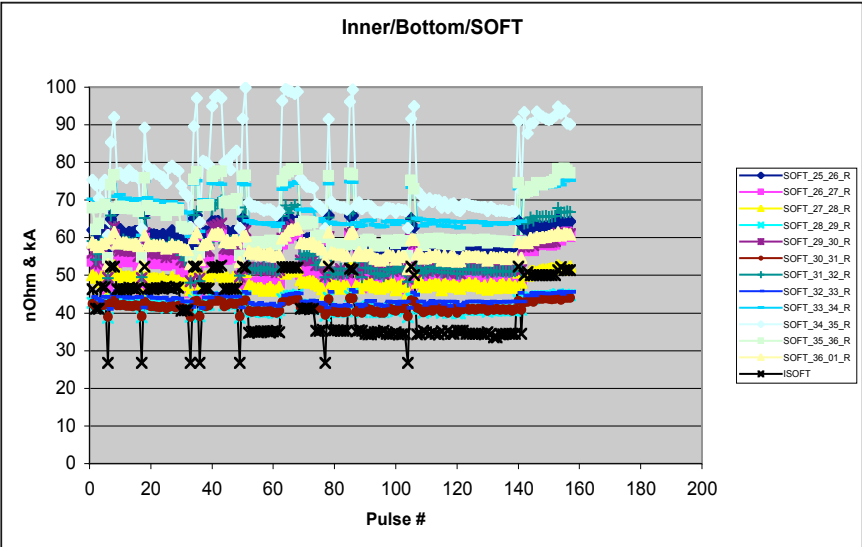
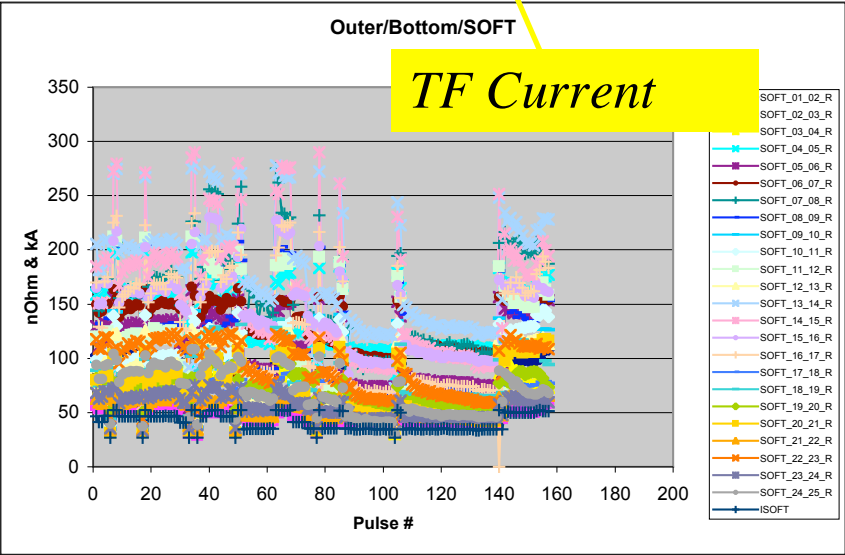
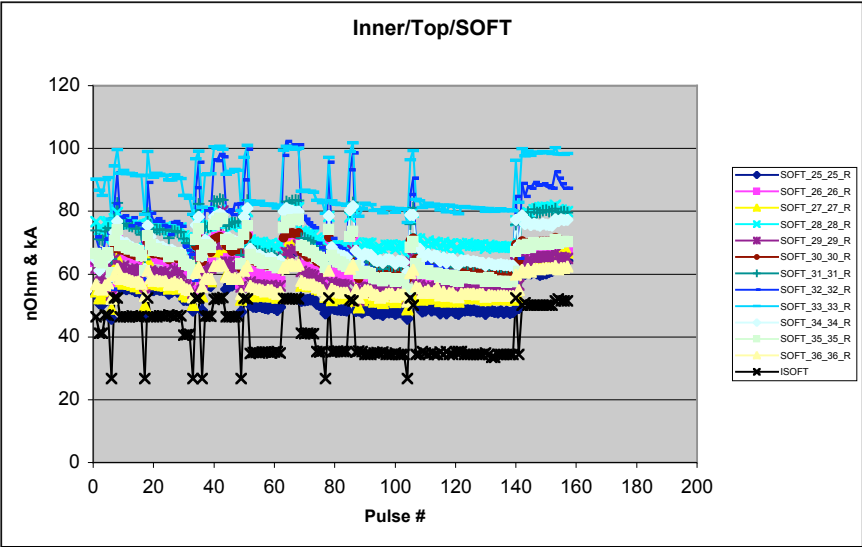
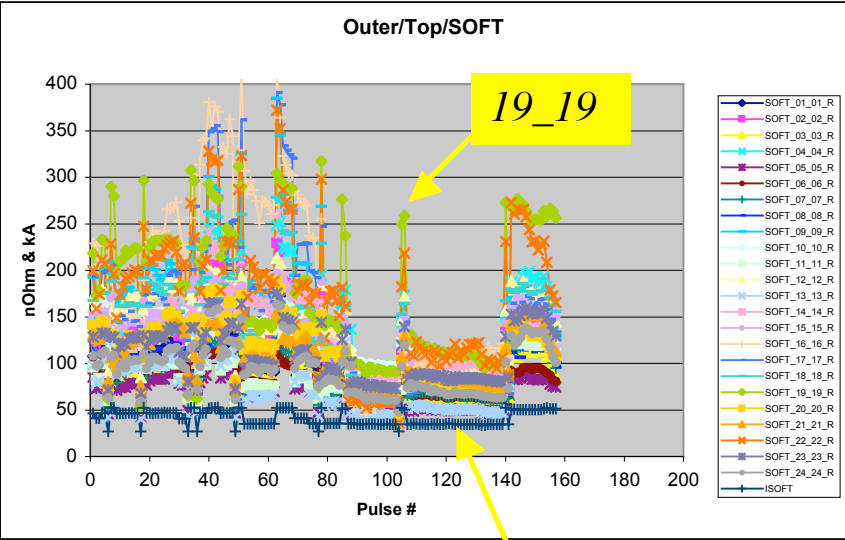


Some early data did not have clean TF-only pedestal



SOFT Trend

Last 200 shot #'s



Summary

1) After 250 shots at $Bt \leq 4.5\text{kG}/1.0\text{ sec}$, TF joints are sound and stable

@ full I2T we have... $4.5\text{e}9\text{A}^2\text{-sec} * 200\text{e-}9\text{ohm} \sim 1000\text{W-sec}$

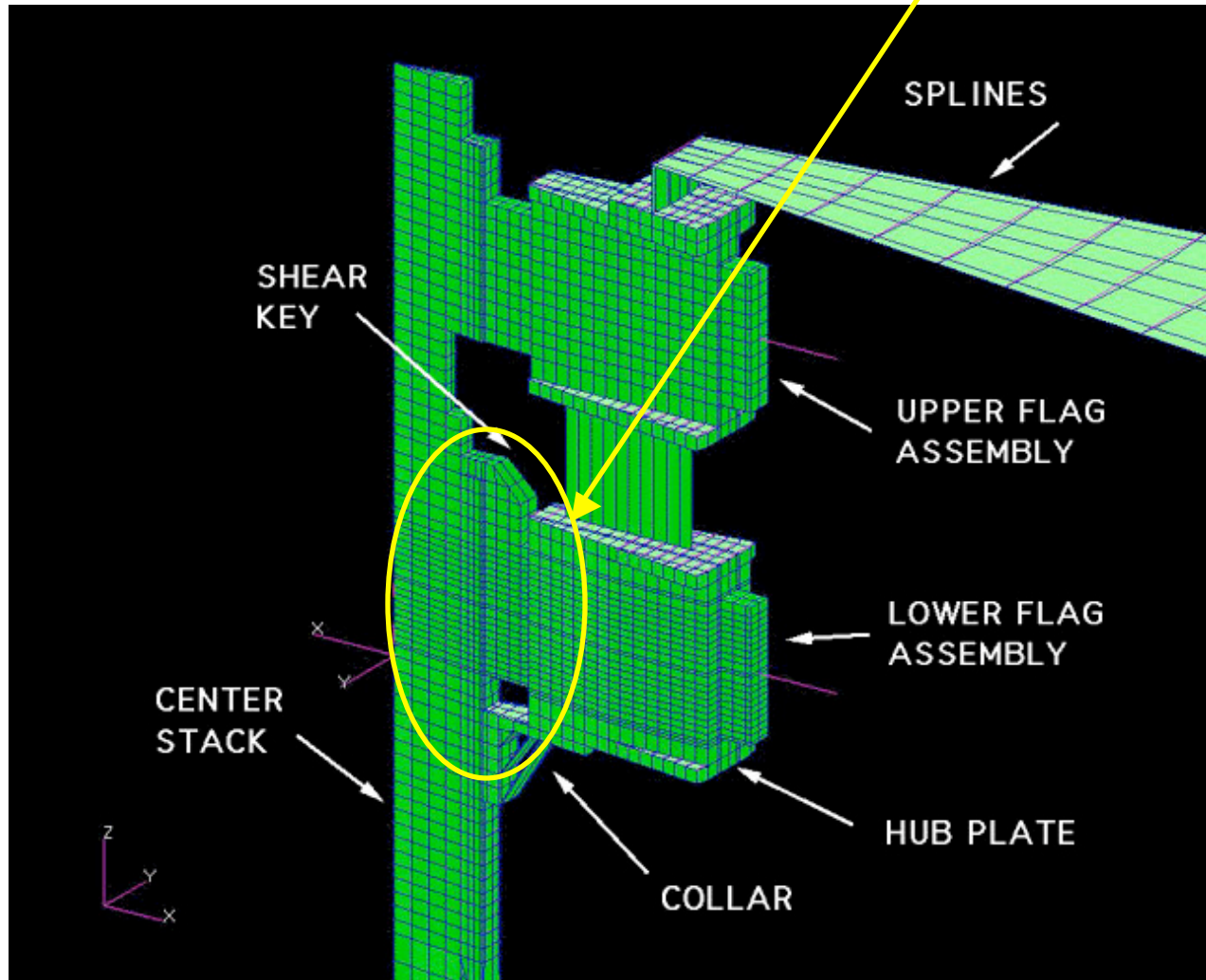
2) Difficult nano-Ohm resistance measurements have been successful

~ 200x resolution of prior method

3) Refinements of FEA models are needed to benchmark against measurements

4) Joint-joint variations exist, but min/max depends on case (200A/SOP/SOFT/EOFT)

Need to Develop Spin-off FEA Models to Capture Detailed Behavior at Joint Where Probes Are Located



Issues & Follow-On Work

(R. Woolley, I. Zatz)

- 1) Develop FEA models of joint locality with finer mesh
- 2) Measure joint resistance vs. pressure of prototype flag
- 3) Using 1) and 2), benchmark model vs. measurements
- 4) Repeat prototype test
 - reconsider method of force application to better simulate real condition
 - vary in-plane and out-of-plane loads and measure resistance
 - run high current test?
- 5) Based on all the above, and consideration of measurement variability, develop definition of allowable for TF operation (6kG)